REPORT

FINAL REPORT

IDENTIFY, EVALUATE AND RECOMMEND IN THE NEXT GENERATION OF RESPIRATORY PROTECTION (RESPO 21)

To

U.S. Army Chemical Research, Development, and Engineering Center

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IDENTIFY, EVALUATE AND RECOMMEND MATERIALS FOR USE IN THE NEXT GENERATION OF RESPIRATORY PROTECTION (RESPO 21)

Final Report

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MATERIALS AND FABRICATION METHODS
For the Next Generation of Respiratory Protection (Respo 21)

Final Technical Report
CBIAC Task 177

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by

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1. INTRODUCTION

Background and objectives

The Army Chemical Research, Development and Engineering Center (CRDEC) is engaged in the development of the next generation of respiratory protection (RESPO 21). This involves identification, evaluation and selection of the best available materials for:

Task 1. Hardcoating for polycarbonate lenses
Task 2. Coated fabrics for use as hoods
Task 3. Facepiece seal, suspension and nosecup for a RESPO 21 softshell concept
Task 4. Materials for a transparent facepiece concept

These tasks were performed by a review of materials and fabrication processes in the literature, and by personal contacts with potential suppliers' engineering and product development personnel. We also contacted knowledgeable personnel at Edgewood Arsenal, Natick, MTL and other agencies. Samples of promising materials were requested and given a preliminary evaluation, and ones that appeared to have good potential were forwarded to CRDEC for their examination and testing.

SUMMARY AND HIGHLIGHTS OF THE PROGRAM

Although excellent protective items have been developed in the past, it has become very apparent that there is an urgent need for better masks, hoods, and garments that will protect soldiers and civilians from the chemical threats of terrorist groups and countries. There is much room for improvement in performance and cost in order to make the protection more readily available for military personnel and for mass distribution to civilians. We have prepared an overview of currently available materials and fabrication methods, and have recommended materials and methods that should be considered for future improvements in this field. This overview is presented in addition to our report on the four tasks that were given to us in the statement of work for this program.

In summary, we submitted more samples than were required by the work statement. Many of these samples should perform well in the designated applications.

For Task No. 1, we submitted 8 samples during this program and two more samples are enclosed with this report. The 8 samples were tested for agent resistance by Battelle; Gentex Corporation's HC-20 and HC-30 coatings showed good agent resistance. The abrasion resistance tests are scheduled to be completed at a later date. Table I lists the samples that we submitted. Table V. was given to us by Mr. Grove, and this shows data on polycarbonate coatings that were tested by Battelle; some of these coatings had good resistance to abrasion and chemical agents. We recommend that you rush testing the sample that we are sending with this report; a 2-inch square laminate, thin glass on polycarbonate, which should show excellent performance. We also discuss and recommend below, that you consider the use of an alternate material for polycarbonate, Swedlow's GAC-590.

For Task 2, we were successful in locating and obtaining many samples of materials that are being used in commercial applications for protective garments for chemical plant personnel. Typical materials are Tyvek laminated with Saranex, and Tyvek coated with Dupont's Barricade. We also obtained samples of DuPont's Kalrez rubber, which has a chemical structure similar to Teflon and therefore has excellent chemical resistance. In addition, we have enclosed with this report, 4 fabric samples, manufactured by CQ Corporation, that have a proprietary treatment for chemical resistance.

For Task 3, we were successful in locating interesting structures of polyurethane film laminated onto Lycra fabric, manufactured by Fabrite Corp. Our Project Officer, Mr. Corey Grove examined this material and reported to us that it appeared to be a good candidate for this application. Mr. Grove used this fabric for fabricating some trial parts.

One highlight of our work for this program was our lab preparation of sample masks/hoods that were fabricated by flow coating a latex polymer onto a mandrel that had been supplied to us by Mr. Grove. A stretchable fabric was draped over the mandrel, so that the final product was reinforced and resistant to tearing. We developed a bonding procedure for bonding an optically clear polyurethane lens, a filter, and a flutter valve to the latex coated fabric structure. We located and conducted trials with a butyl latex and a fluoropolymer latex; these materials could lead to convenient and cost effective coatings and methods for rapid production of agent resistant products.

For Task 4, we submitted a number of fluoropolymer and polyurethane based film samples. Also, the concept of a peelable multilayer for quick decontamination has been suggested in the past, and a sample of thin layers of optically clear polypropylene film (Permacel J-Lar tape) was submitted as an example of this concept. In addition, we located TPE's (thermoplastic elastomers) with good optical clarity, and this class of materials should lead to very good candidates for transparent facepiece applications.

We have enclosed with this report, 3 samples of Shell Chemical Company's Kraton rubber. Some of these Kraton samples have improved optical clarity and this is discussed in detail in Section 2.

In a following section, we have listed candidates for the seal, facepiece and barrier layer materials that should be considered for this application.

2. DISCUSSION OF MATERIALS AND FABRICATION METHODS

The following section provides an overview of materials and fabrication methods that are pertinent to the field of respiratory protection.

2.a. Lens Materials

The transparent lens materials that have been used for protective masks and hoods have been either rigid, including glass, acrylic, polycarbonate, and CR-39; or flexible, including vinyl plastic, polyurethane elastomer and silicone rubber. Task 1. of this program has been mainly concerned with polycarbonate, since this rigid plastic provides a good balance of performance; it has good impact resistance, good optical properties, relatively low cost, and easy to mold. However, it does have deficiencies, including poor abrasion resistance, poor chemical resistance, and susceptibility to stress crazing. Therefore, it must be coated, and our objective during this program was to obtain samples of coated polycarbonate that would perform well in abrasion and agent resistance tests. The target abrasion resistance was to pass a Taber Abrasion test that involved 2000 cycles at 500 grams load. This is a difficult requirement and many state-of-the-art coatings will not pass this test. However, during the program, we received information that Battelle had tested some coatings that passed this abrasion test. Also, some of the coated samples that we submitted during this program will probably pass this test. Therefore, this may be an appropriate time to look toward coatings and materials that may exceed the requirements that were stated for this program.

During this program, and in a later section of this report, we have discussed the advent of diamond coatings. Even though there is a problem with the optical clarity of the current diamond coatings and with high glint, this technology should be followed for possible application as a lens coating material.

Another candidate, discussed below, is the possible lamination of a thin glass layer onto a polycarbonate lens. A sample of this type of laminate is enclosed with Mr. Grove's copy of this report. A glass/polycarbonate laminate has been used as an aircraft transparency. Sierracin/Sylmar, Sylmar, California 91342, manufactures this type of curved windshield for the U.S. Air Force B-1B Aircraft and for IAI's Westwind Astra Executive aircraft.

A material that should be given more consideration as a substitute for polycarbonate in military lenses is GAC-590, manufactured by Swedlow, Inc. of Garden Grove, CA. This material is a water-clear, cross-linked, aliphatic polyurethane that has good chemical agent resistance. It has good optical and mechanical properties, abrasion and outdoor weathering resistance. A report on this material was presented at the Conference on Aerospace Transparent Materials and Enclosures, January, 1989, by Mr. John Uram, Loral Defense Systems and Mr.

Stephen Sandlin, Swedlow. An important point to consider here is that the Taber Abrasion test may not be as good an indicator of actual performance of a mask lens during service, as would be a falling sand test. In the latter type of test, the tough aliphatic polyurethanes will usually perform better than the more rigid type of materials or protective coatings.

Note in the following table, that the Taber abrasion resistance of GAC-590 is much higher than polycarbonate and other clear materials.

MATERIAL	CHANGE-IN-HAZE
GAC-590	3.0
ACRIVUE 350[3]	34.6
POLYCARBONATE[4]	36.7
POLYARYLATE	25.7

1. ASTM D-1044. 100 revolutions, 500 G load
2. ASTM D-1003, Change in percent haze
3. MIL-P-8184 Acrylic
4. MIL-P-83310

The above table was published in a report titled "GAC-590, An Aerospace Transparency Material", co-authored by Mr. Stephen Sandlin of Swedlow, Inc. which was presented at the Conference on Aerospace Transparent Materials and Enclosures, January, 1989 in Monterey, California.

2.b Mask and Hood Materials

In past and current protective devices, many different materials and fabrication methods have been used. Rubbers that have been used to fabricate masks have included natural rubber, bromobutyl, butyl, neoprene, and silicone. The latter has been used in spite of the fact that it is a poor permeation barrier material, because it has other excellent properties such as low compression set, retention of flexibility at low temperatures, and non-irritation to the skin. In actual use, a silicone faceblank would have to be covered by a protective hood in order to afford resistance to agents such as nerve or mustard gas.

Butyl-coated-nylon has been extensively used for military hoods and protective clothing, and may be considered an excellent control or comparison product for future candidate materials. Butyl rubber is a conventional rubber that must be heat vulcanized. Butyl-coated-nylon has shown some problems with aging cracks and EXXON has made some recent improvements in butyl rubber and its compounding that should be considered for future use. The primary fabrication method for current hoods and garments has involved cutting patterns and sewing. The sewing process creates holes in the materials and these may create leakage paths unless carefully sealed by coating with butyl polymer or other means. Also, the sewing process is relatively expensive and slow, since it joins the material at a single point - even though the sewing point can move fast by use of a machine.

During recent years, thermoplastic elastomers (TPE) and thermoplastic olefins (TPO) have been replacing the conventional rubbers in many applications. These materials can be fabricated by the convenient and rapid thermoplastic processing methods, such as injection molding and extrusion, instead of the slower processing methods of conventional rubber vulcanizing, such as transfer or compression molding. Also, the TPO's are heat sealable and have the potential of providing good chemical resistance and permeation barrier properties. Exxon has developed a butyl thermoplastic elastomer, Trefsin.

During this program, we have been searching for optically clear thermoplastic elastomers (TPE's) that would be good candidates for a transparent facepiece (Task 4.). Mr. Katz attended an American Chemical Society, Rubber Division meeting in Washington on October 11th 1990. In that meeting, some papers were presented on TPE's. Some of the relevant papers are mentioned in section 2.e. In this meeting, Mr. G. Holden of Shell Development Company mentioned that his company is manufacturing TPE's with improved optical clarity that can be used alone or blended with clear polypropylene to obtain varying elastomeric properties. We received some of these samples just before this final report was completed, and they are enclosed with the original copy of this report. Shell Development Company does not manufacture films of this material, but they do produce sample quantities. We received a small sample of Kraton G, Grade RP6549, which has much better optical clarity than their standard grade G2730X. The thin film that we received is 3-mils thick and has haze over most of the film, but it is very rubbery and distant objects can be seen through the film. It would be advisable to consider an R&D program to extrude mixtures of this material with varying ratios of optically clear polypropylene, and then surface treat the optimum clarity films or sheets to improve the permeation barrier properties. There are many different grades of Shell's Kraton thermoplastic elastomer; many of these grades were developed for specific fabrication methods. Grades D2103 and D2104 have good optical clarity and these are injection molding grades; G2701 has good optical clarity and is an extrusion resin. Other grades have been developed for blown film and for blending with polypropylene.

Another exhibitor at the ACS, Rubber Division meeting was GLS Corporation, a distributor of Shell Kraton products. A representative of that company told us that Caldwell Gasket, Auburn, Kentucky is manufacturing films of high clarity Kraton. We requested and received samples of their product G2712. The samples are injection molded plaques, 1/8-inch thick. Although they are translucent, rather than optically clear and have a high degree of haze, this material may have satisfactory optical quality for use as a lens in a thin film of 10 to 20-mils thickness.

Airco Coating Technology of Concord, California, has developed a new coating technology, a process of Plasma Enhanced Chemical Vapor Deposition (PECVD) of SIO_x (with x is greater than 1.7), amorphous, and optically clear, which "adhered well without pretreatment to the surface to be coated". This excellent barrier coating, which can be applied to various substrates, should be considered for agent resistance applications. Although it is not readily available now (October, 1990), Airco reports that they have already set up lines for production coating of sheet material and commercial plastic bottles. The product development manager is Mr. Adam Rizika and he may be reached at (707) 423-2100.

Fluoropolymers are important candidate materials for respiratory protective devices. The best known fluoropolymer is Teflon (polytetrafluoroethylene), which has superior resistance to all of the usual chemicals and agents. A Dupont rubber, Kalrez, is based on a polymer similar to Teflon and we have mentioned this product in other sections of this report. We submitted samples of Kalrez for testing during this program. Unfortunately, Dupont does not sell Kalrez gum stock for molding, but only provides finished products such as "O-rings". DuPont's Viton and 3M's Fluorel are highly fluorinated rubbers that have shown good permeation resistance to chemical agents. An important deficiency of most Viton and Fluorel grades is poor low temperature flexibility. Also, most formulations exhibit swelling or attack by some chemicals, such as methyl ethyl ketone. A line of potentially high performance fluorinated polymers have been studied during the past 15 years by Dr. James R. Griffith, Naval Research Laboratory, Washington, D.C. These products have included fluorinated epoxy and polyurethane resins. An article published by the American Chemical Society in 1986[6], titled "Fluoroepoxy Resin for Moisture Vapor Barrier Coating and Other Applications" describes the excellent vapor barrier properties of the fluorinated polymers.

2.c Computer Programs

During our last program, we had provided information about a Technical and Reference Manual "Guidelines for the Selection of Chemical Protective Clothing" sponsored by U. S. Environmental Protection Agency and U. S. Coast Guard and prepared by Arthur D. Little Inc. ASTM also has information on protective clothing materials. During this program, we requested and received ASTM standard test methods for Resistance of Protective Clothing Materials to Permeation by Liquid and Gases, Specifications F739-85 and F903-87. ASTM has a Committee on Protective Clothing, F-23. Another book, "Chemical Protective Clothing Performance Index" by Krister Forsberg and Lawrence H. Keith, includes the selection materials on the basis of breakthrough time and permeation rate for different applications. The same authors also have a computer program for selecting materials, called GLOVES+.

An article published in the October 1990 issue of Modern Plastics, describes some of the database and computer programs available for the selection of materials. In Figure 1. Various Materials Databases, it is apparent that there are already many computer programs that will help in the selection of an appropriate material for a specific application. However, we believe that there should be a new compilation of a database that is specifically designed for the selection of materials for the fabrication of protective masks and hoods. This information should include permeation rates, and also decontamination characteristics, along with physical properties, resistance to chemical agents and approximate cost.

It appears to us that there is a lot of information about the characteristics of many films and fabrics for use in protective garments that may not have been accumulated by either Edgewood, Plastec, Battelle, or Natick. Some of this data may be useful in future decisions for Army masks, hoods, and clothing. All of this information should be on a computer program, which should have a menu that permits the user to intract with the program and make materials choices for his specific application.

2.d Fabrication Methods

Selection of an appropriate fabrication methods is as important as the selection of materials for a particular application. In the past, sewing was a primary method that was used for the fabrication of butyl rubber based hoods and masks. As discussed above, this method has many disadvantages. During this program, we proposed a dip molding method for making hoods and masks, and the details are given in addendum 1. Also, we suggest that conventional rubber can be replaced with thermoplastic elastomers so that heat sealing can be used instead of sewing. The thermoplastic elastomers can also be injection molded with rapid cycles instead of the slower compression molding cycles of conventional rubbers.

Another fabrication method that should be considered for protective masks and hoods is blow molding, which provides very rapid molding cycles[5]. A transparent-polymer-parison such as a transparent Kraton polymer, can be used in order to obtain a product with good optical clarity. Inserts, such as filters and flutter valves, can be adhesive bonded, heat sealed, or mechanically crimped onto the thermoplastic elastomer.

2 e. REFERENCES

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4. Gage, Paul D., "TPE Blown Film Processing & Properties", Consolidated Plastics Company, Presented at Rubber Division, American Chemical Society meeting October 9 - 12, 1990.

5. Abell, W. R., Stuart, R. E., Myrick, R. E., "Blow Molding of Melt-Processible Rubber" E. I. du Pont de Nemours, and Co. Inc., Presented at Rubber Division, American Chemical Society meeting October 9 - 12, 1990.

6. Lee, Sheng Yen; Griffith, James R., "Fluoroepoxy Resin for Moisture Vapor Barrier Coating and Other Applications," Industrial Engineering Chemistry, Product Research Development, American Chemical Society, December 1986, pgs.572-577.

The following sections present our findings and recommendations for each of the four tasks that were in the work statement of this program.

3. TASK 1. HARDCOATINGS FOR POLYCARBONATE

Among the approaches to hardcoating polycarbonate lenses are the following methods: organic coatings such as highly cross-linked UV curable acrylics, aliphatic polyurethane or epoxies; inorganic coatings such as siloxane, silica or diamond; and bonded overlays such as thin glass.

Polycarbonate plastics such as GE's Lexan have the highest impact resistance of the usual lens materials, and thus are very attractive for safety glasses or military mask lenses. However, they also have unacceptably poor scratch abrasion and chemical resistance, so all commercial polycarbonate lenses are "hardcoated" with some material such as a siloxane. The hardcoating improves the scratch resistance considerably; but unfortunately it also degrades the impact resistance, particularly if it is applied to the back side of the lens (which it is, since it is usually applied by dip-coating). Consequently, the commercial polycarbonate coating formulations are compromises between scratch resistance and impact resistance.

Most ophthalmic firms have their own proprietary hardcoating formulations, which they do not disclose. There are some coating materials such as the Exxene S-28 & S-30, Gentex HC-13 & HC-20, Panelgraphics 911, Mobay HC-500, GAF Corp's GafGuard 233 etc. that are available for purchase. These coatings were submitted for agent and abrasion resistance test during this program. Recently, we received some agent test results done by Battelle, but all of the abrasion resistance tests have not yet been completed. The results are summarized in Table I. Agent test results indicated that Gentex Corp's HC-13 and HC-20 coatings have very good resistance to agents. The abrasion resistance tests are scheduled to be completed at a later date. Table V. was given to us by Mr. Grove, and this shows data on polycarbonate coatings that were tested by Battelle; some of these coatings showed good performance.

None of the organic coatings can yet equal glass in scratch resistance. Numerous groups are attempting to develop coatings of the hardest substance, diamond. Great claims are being made, but we have yet to see any actual samples that are transparent and free of haze. Moreover, there are some inherent problems with diamond and diamond-like coatings. Even the best of them tend to be hazy because they are microcrystalline; and we have seen some that were actually black and opaque. In addition, the high refractive index of diamond gives about double the surface reflection and glint of plastic or glass. And of course diamond coatings are still extremely expensive. During this program, we tried to obtain a free sample of diamond coating on polycarbonate from several companies but were not successful. We received literature from Beam Alloy Corporation and Air Products (now called Diamond Axe Corporation) and forwarded this information to Mr. Grove. Both companies informed us that they would perform a trial run at a cost of $2000. This is an option that you may wish to consider in the future.

A number of Small Business Innovation Research (SBIR) Phase I DOD awards were given to small businesses for investigations related to diamond films and coatings. These companies included Advanced Technology Materials Inc. for Diamond films Photoconductive detector, Aerodyne Research Inc. for fluorinated diamond thin films for tribological application, Crystallume for chemical vapor deposition diamond films for tribological application; and there were a number of awards for diamond films.

The situation is similar with silicon and silicon oxide coatings. A number of laboratories are working on them, and great claims are being made; but samples and demonstrations are not forthcoming when one inquires.

Perhaps the simplest, best and cheapest coating would be a thin layer of ordinary glass. Glass is available, cheap, hard, and has no more glint than the plastic lens itself. It is commercially available in 3-mil, 7-mil and 10-mil thickness from Corning Glass, and it can be bonded onto polycarbonate lenses with a clear urethane or silicone adhesive. Bonded onto the front of the lens, the glass would contribute its outstanding scratch and abrasion resistance, while the bare back surface of the polycarbonate lens would retain its outstanding impact resistance.

Of course, the lens is curved, and the glass comes flat, so the glass has to be curved to fit. This is readily done by heating the glass to the softening point in a furnace and allowing it to "slump" against a suitable mandrel. A similar process is currently under development by an associate of ours (John Brown Associates) in Stirling, NJ, for laser-protective glasses.

With this report, we are sending an acrylic sheet coated with Techguard hard coating from American Optical and a polycarbonate sheet faced with a sheet of 7-mil glass. These are the 9th and 10th materials that we have sent for Task No. 1.

4. TASK 2. HOOD MATERIAL

Butyl rubber has been the standard hood material. Although butyl rubber has performed well for hood applications, there have been some problems with its use in clothing. In particular, the Butyl TAP Suits have encountered cracking and flaking problems. There have been crazing and premature failures, typically in the armpits and crotch areas. Exxon has developed improved butyl formulations. Some of these have a treated talc filler instead of the standard mineral filler and initial results indicate less moisture absorption, better tear strength and physical properties with lower permeation rates. Archer Rubber Company is involved in tests for this application. Exxon has also developed modified butyl compounds, including new halo-butyls.

We had planned to make firm recommendations of new protective materials, and to rank the suitability of materials for protective garments. Our criteria for selection would have been improved if we had data related to the performance of the samples that were submitted during this program. Unfortunately, these data will not be available until after the due date for our final report on this program. Therefore, the selection of the best materials is based on our prior data and knowledge of agent test results of these types of materials. In Table II, we have summarized the performance rating of the samples submitted during this program and comparison with ratings of other materials. In **all our tables, our ratings are very arbitrary and should not be used as a precise guide to the value of a material for a specific application.**

During this program, we requested and received a sample of EYPEL-F elastomers from Ethyl Chemicals Group. The material is a fluorophosphazene elastomer and has excellent low temperature properties (brittle point -68C) in contrast to most grades of Viton and Fluorel elastomers that become brittle at moderately low temperatures. Ethyl Corp. Special Chemicals Division is located in Baton Rouge, Louisiana and the phone number of their customer technical service is 504/768-5940. We had submitted a 4x4 inch laminate of EYPEL-F to polyester fabric to Mr. Grove for chemical agent testing. We feel that this will be a very good choice for a hood material, but we would like to see permeation data, especially with regard to nerve gas, before we could recommend this material for CB applications.

Among the commercial products that reportedly have good chemical resistance so that they are used for protective suits in the chemical industry are the following materials: Tyvek coated with DuPont's Barricade which we received from Mar Mac Manufacturing Co.; Challenge 5200 composition fluoropolymer/glass fiber/fluoropolymer received from Chemical Fabrics Corporation. The permeation barrier properties of these materials versus agents should be tested and performance compared with current military protective materials.

Enclosed with this report are 4 fabric samples that we received from CQ Corporation, E.Rutherford, New Jersey. The fabric (cotton, nylon or polyester) has a proprietary treatment for permeation resistance. A description of each fabric is given in Table II. Task 2. was to identify, evaluate and select the best available material for coating fabrics for use as hoods. As a result of our search and requests, we received many samples that were pertinent for this task.

5. TASK 3. SOFTSHELL CONCEPT

Task 3. involved obtaining samples that will be candidates for the facepiece seal, suspension and nosecup of the RESPO 21 softshell concept. For this task, we submitted 19 samples. In Table III, we have summarized the performance rating of the samples submitted during this program. The rating of materials is based on our prior data and knowledge of agent test results of these types of materials.

One of the candidate materials that we located was Fabrite Corp's Lycra laminated with polyurethane film. Our army project officer, Mr. Corey Grove, examined this material and reported to us that it appeared to be a good candidate for this application. Mr. Grove used this fabric for fabricating some trial parts. We were told by the manufacturer that they will be agreeable to produce large quantities for the Army in any color that is specified.

In the literature, it has been reported that surface fluorination improves the permeation barrier properties of a material. Air Product Corporation is using surface fluorination treatment for perfume bottles. We contacted Air Products for surface fluorination of polyurethane to improve the chemical resistance. We obtained samples with different levels of fluorine surface treatment. Surface fluorination was done on both Stevens clear urethane and Fabrite Corp's Lycra/ polyurethane laminate by Air Products. This surface treatment had no apparent effect on optical clarity, and should increase the chemical resistance of the polyurethane. These samples were submitted to Mr. Grove.

During this program, we requested, received and experimented with four types of latex materials; natural rubber latex (104L), fluoropolymer latex (TN latex), Butyl latex (BL-100) and polyisobutylene latex (PIB-500). Coated fabrics with each latex and combination of latices were submitted to Mr. Grove for agent testing. We have not received the agent permeation results, but we believe the combination of fluoropolymer latex and natural latex will give the best results.

A dip molding concept to make hoods was presented by Mr. Katz at the meeting. A sketch of the concept is attached to the report as Figure 2.

We did some lab experiments related to making full sized masks, by using the second of two mandrels that we received from Mr. Grove. We designated this mandrel as Edge #2. Our fabrication method was to wrap a stretchable fabric over the mandrel, and flow coat the fabric with a natural rubber latex. Our final trials were shown at the July 26th meeting and then were given to Mr. Grove. A brief description of the fabrication method and our comments on these trials was presented at the July 26th meeting and a write-up on Dip Coating is attached to this report as Addendum 1. This hood dip fabrication process could lead to lower cost and better protection.

6. TASK 4. TRANSPARENT FACEPIECE

Task 4 was to identify, evaluate and select the best available materials for the transparent facepiece concept, and we submitted 25 pertinent samples. In addition, we have enclosed with this report, 3 film samples of Shell Chemical Company's Kraton rubber. In Table IV, we have summarized the performance rating of the samples submitted during this program. The rating of materials is based on our prior data and knowledge of agent test results of these types of materials.

Fluoropolymers have properties that make them good candidates for CB protection applications. Many fluoropolymers have low permeation rates, surfaces that are nonwettable by most liquids, and excellent resistance to most chemicals. Some fluoropolymers have good optical transparency and low temperature flexibility.

Among manufacturers of fluoropolymers are Dupont (Teflon, Viton), 3M Co. (Kel-F, Fluorel), Allied Signal Engineered Plastics (Aclar), etc.

Decontamination of protective gear and clothing is a major concern and during this program, we discussed a concept that had been proposed before; multiple peelable surface layers as part of a transparent facepieces. Some of the materials that have low permeation rates may present even greater decon problems than higher permeation rate materials. A possible solution to this dilemma would be the use of thin outer layers that can be removed after exposure and discarded, so that the gear or equipment could immediately be placed back into use. These peelable layers could be low cost polypropylene films, which have good resistance to many chemicals, or a Saranex film or a fluoropolymer film. Even though the latter have a relatively high cost per pound, the thin films that could be used may still be cost effective.

During this program, we submitted a four layer laminate as our recommendation for Mr. Grove's transparent facepiece concept. The first layer was polycarbonate (15 mils), second layer Stevens urethane (10 mils), third layer Hercules polypropylene (5 mils) and fourth layer DuPont fluoropolymer film. All these layers were bonded together by using a transparent 3M unsupported adhesive film.

We had also submitted samples of a multilayer laminate for the peel-off concept that we prepared by use of J-Lar Adhesive Tape from the Permacel division of Johnson & Johnson. J-Lar Tape had excellent transparency; a roll of tape about 1/2-inch thick has water-clear transparency so that the legend on the tape core was as legible through the tape as if the tape were not there. The samples had a four layer J-Lar laminate on a 10-mil thick optically clear JPS Elastomers polyurethane film.

The concept of a peel-off strip on a lens is similar to the "tear-off" strips that race car drivers use. We submitted to Mr. Grove, samples of this type of product, obtained from D.J. Manufacturing, Harbor City, CA. They manufacture Simpson Race Products Helmets, and some of these helmets use tear-off strips. The manufacturer of the "SUPERTHINS Tear-Offs", is Rose Racing Products, Inc., Forney, Texas 75126. Their phone number is 800/222-8900. This product does not involve a pressure sensitive adhesive, but is a simple "stack" of thin film layers; the outer layer can be removed quickly by the race car driver when it becomes too dirty to see through. In a gas mask application, it would seem desirable that the separate layers should be bonded with a pressure sensitive layer, such as illustrated by the J-Lar film.

The polypropylene based materials are good candidates for hood materials, clothing, and flexible lens. Mr. Shoemaker pointed out the fact that polypropylene was one of the best materials with regard to decon characteristics. The related olefinic thermoplastic elastomers will probably have good capability for decon, could be made as a multi-layer peel-off structure for various protective hoods and clothing designs.

7. CONCLUSIONS AND RECOMMENDATIONS

During this program, we had hoped to make a narrow selection of the best one or two materials for each of the 4 tasks that were assigned to us, and to give specific reasons for our choice. However, there was a major problem in obtaining agent resistance tests before the end of our contract, so this important factor prevents us from narrowing the field of materials choices for each application. Therefore, we list below a number of good candidates for each task, and the advantages and disadvantages of most of these materials have been indicated in our discussion above. The choice will now depend on the mission anticipated for the end product, which will lead to a proposed product design and then the choice of one or more of the candidate materials below for screening tests and then final selection. An important potential candidate, fluorinated surface treated olefins, may be an excellent choice, but we have not included it below because the permeation data has not yet been completed.

TASK 1. HARD COATINGS: DIAMOND COATINGS, GLASS-POLYCARBONATE LAMINATES, SILOXANES, ALIPHATIC POLYURETHANES.

TASK 2. HOOD MATERIALS: BUTYL RUBBER, KALREZ, POLYURETHANE, EYPEL-F

TASK 3. SOFTSHELL CONCEPT: TN LATEX, BUTYL LATEX , BUTYL RUBBER, KALREZ, POLYURETHANE, EYPEL-F FABRITE'S URETHANE FILM/LYCRA LAMINATE

TASK 4. TRANSPARENT FACEPIECE:

a. Seal: KRATON
b. Barrier layer: TEFLON FEP, TEFZEL
c. Facepiece: ALIPHATIC POLYURETHANE, BATTELLE EPDM

In past and current protective devices, many different materials and fabrication methods have been used. A comparison and a brief discussion of these fabrication methods was given in prior Section 2., Discussion of Materials and Fabrication Methods. On the basis of our experience and the availability of materials, we suggest the following methods of fabrication for the Tasks 3, and 4.

TASK 3. SOFTSHELL CONCEPT: DIP COATING, HEAT SEALING

TASK 4. TRANSPARENT FACEPIECE: THERMOPLASTIC INJECTION MOLDING AND BLOW MOLDING.

8. SUGGESTED CONTINUATION PROGRAMS:

Recently, there were newspaper photos of a transparent Israeli children's hood and a protective suit. These photos are shown in Figures 3. and 4. These types of designs should be studied and considered for low cost emergency protection of soldiers and civilians.

As indicated above, there have been many good choices of materials and fabrication methods for protective devices, but there is room for great improvements in this field. We recommend that there should be an investigation of the subjects listed below in order to provide information that will lead to great advances in this important field.

An excellent production method for high-performance low-cost masks/hoods will be dipcoating. We recommend that the latex dip coating process should be investigated, and this should proceed soon to pilot scale production of actual units. There are many factors to evaluate for this process. Among these are whether or not a fabric should be draped over the mandrel. Which latex material or combination should be used, since natural rubber provides the highest strength and is the easiest to use, whereas the butyl latex or fluoropolymer latex provides a better permeation barrier. The choices of mandrel contour and insert designs must also be made.

We have located a company in Akron, Ohio that has excellent lab equipment and production equipment for automated molding of latex products such as gloves and condoms. They also do pilot runs for dip moldings. We suggest that you consider a future contract that would be directed toward a pilot run of hoods or masks that would be produced on this type of automated dip coating equipment. We would be pleased to have the pilot line set up in our lab to conduct these experiments, which should include the use of the fluoropolymer latex blends with natural rubber latex as we had tested in this program.

Another important area to be investigated is the surface treatment of various materials in order to improve their resistance to agent penetration. In the literature, it has been reported that surface fluorination improves the permeation barrier properties of a material. Air Product Corporation is using surface fluorination treatment for perfume bottles, and their data indicates great reductions in the permeation rate of the organic fragrance out of the bottle. From this type of prior data, we anticipated that the fluorination process would improve the chemical resistance of polyurethane, Kraton rubber and other materials. Therefore, during this program, we had submitted samples with different levels of fluorine surface treatment. The details are given above in the Task 3. section. We recommend a continued investigation of surface fluorination by the Air Products method, plasma polymerization and other means. Different levels of fluorination should be tried with various pertinent transparent polymers such as Kraton, Battelle's EPDM and polypropylene.

There is a company that is marketing high density polyethylene (HDPE) bottles that have been surface treated with fluorination. We recommend that some of these should be tested for agent resistance along with equivalent non-treated bottles. The company is Step Products Inc., Woodstock, IL60098, phone 800-338 4810.

Other surface treatments such as plasma enhanced chemical vapor deposition (PECVD) silicon oxide coatings and surface chlorination should also be investigated.

The fluorinated polyurethanes and fluoroepoxy resins that have been studied by Dr. J.R. Griffith at the Naval Research Laboratory should be investigated for many potential applications in respiratory protective devices for the military. The fluorinated epoxy resins may soon be commercially available from Allied Chemical Corporation, Morristown, NJ.

In prior Section 2., Discussion of Materials and Fabrication Methods, a comparison and a brief discussion of fabrication methods was given. There are some advantages of blow molding over other molding processes, such as injection or compression molding. The blow molding process is described in the article cited in Reference #5. We recommend that the blow molding of a transparent grade of a TPE or TPE/polypropylene blend should be evaluated for production of masks and hoods. This should be combined with a study of the surface treatment of the formed product by a process such as fluorination, in order to improve the permeation barrier properties of the optically clear TPE.

9.0 CLOSING REMARKS

A program of this type will be more effective if agent resistance tests can be run within a short time cycle on candidate coatings and materials, so that the best materials can be selected for further improvement and successive rounds of agent resistance tests. We recommend that a company such as Geomet Technologies, Inc., Germantown, Md., should be included in any future development program as a testing means for reaching firm conclusions on the best materials for agent protection. Because of limitations in our knowledge of agent resistance, we could not make a narrow choice of the best materials and processes for the fabrication of masks, hoods and garments. However, the facts presented in this report should provide guidance toward good paths to explore in the development of improved products for protection against chemical and biological agents. As noted above, there are recent developments in materials and processes for barrier films that will provide cost effective protection.

A number of pertinent comments that should be considered for future programs in this field, were sent to us in a letter by Mr. Charles Shoemaker. This letter is attached to this report, as Addendum 2. Mr. Shoemaker summarized the main factors that control the design concepts of military protective devices, and stated that "... materials of construction are the principal basis for significant changes...". Also that "thermoplastic materials which exhibit heat sealing, heat forming and ease of decontamination ... offer the potential for ... design and fabrication changes."

If there are any questions regarding this report or any of the items submitted during this program, please contact us. We anticipate receiving or preparing a few pertinent samples in the near future, and these will be transmitted to Mr. Grove.

We greatly appreciate the knowledgeable and considerate liaison by Mr. Grove, Edgewood Arsenal program manager and Mr. Fran Crimmins, Battelle program manager throughout this program. We also want to express our thanks to Mr. Charles Shoemaker and Dr. John A Brown, Consultants, for their constructive help and guidance during this program.

Harry S. Katz

Harry S. Katz
Consultant: Plastics and
Composite Materials

Radha Agarwal

Dr. Radha Agarwal
Research Director and
Program Manager

TABLE I

TASK 1. HARD COATINGS FOR POLYCARBONATE LENS:

TRADE NAME	DESCRIPTION	RATG	COMMENTS
1. Vueguard 911	Panelgraphic Corporation West Caldwell,NJ 07006 201- 227 1500	3	agent test done in HD, no data in GB.
2. Makromol HC500	Mobay Corporation Berlin, CT 06037 800-423 6471	3	,, ,, ,,
3. S-39 AP	Exxene Corporation Corpus Christi, TX 78468 512-991 8391	3	,, ,, ,,
4. HC-13	Gentex Corporation Carbondale, PA18407 717-282-3550	10	no degradation in HD and no results for GB
5. HC-20	,, ,, ,,	3	2 had opaque marks one showed no degradation
6.Paralyene C	Nova Tran Corporation		no agent test results
7.Paralyene D	Nova Tran Corporation Clear Lake, WI 54005 715-263 2333		no agent test results
8.HP92SDB-112	GE Plastics Pittsfield, MA 01201 800-451 3147	2	no results in GB
9. Techguard	American Optical Southbridge, MA01550 508-765 0043		Not tested by Battelle. New addition
10.Glass-Polycarbonate Laminate	John Brown Associates Sterling, NJ 201-647 6890		Not tested by Battelle. New addition

RATG: Performance Rating - 10 excellent and 0 very poor
Performance rating based on Battelle's agent test.

TABLE II

TASK 2. COATED FABRICS FOR USE AS HOODS

TRADE NAME	DESCRIPTION	RATG	COMMENTS
1. Responder	Life-Guard Corporation Guntersville, AL35976 800- 323 2533	6	Poor Stretch, Claimed good chem resistance for industrial suits
2 .Tefguard	,, ,, ,,	5	,, ,, ,,
3 . Neoprene	,, ,, ,,	3	poor stretch
4 . V/N/C	,, ,, ,,	3	,, ,, ,,
5 .Tyvek coat with DuPont's Barricade	Mar-Mac Manufacturing Co McBee, SC29101 803-335 8211	6	no stretch. Claimed good chem resistance. Used in industrial suit
6 . Tyvek laminated with Saranex	,, ,, ,,	4	,, ,, ,,
7 .Chemrel Max	Chemron Inc., Vernon Hills, Il 60061 312-520 7300	5	,, ,, ,,
8 .Chemrel TM	,, ,, ,,	5	,, ,,
9 .Challenge 5200	Chemical Fabric Corp. Merimack, NH03054 1-800-451 6101	6	,, ,, ,,

RATG: Performance Rating - 10 excellent and 0 very poor
Performance rating based on reported chemical resistance.

Table II. Continued.............

TASK 2. COATED FABRICS FOR USE AS HOODS

TRADE NAME	DESCRIPTION	RATG	COMMENTS
9 .Kalrez Film 16 mil thick	DuPont Wilmington, DE 19898 800-527 2601 (Tech) 800-441 9494 (sales)	8	Excellent permeation Barrier
10.Kalrez Film 42 mil thick	,, ,, ,,	8	,, ,, ,,
11.Polyester coated with Eypel-F (polyphosphazene)	Ethyl Corporation Banton Rouge, LA70820 504-768 5600	8	poor stretch excellent permeation barrier
12.TC.S 23	CQ Corporation Rutherford, NJ07073 201-935 8488		Stretch cotton. Stage 2 MP w. foil w. CQ permeation barrier coating.
13. US 2	,, ,, ,,		Polyester treated with CQ permeation barrier coating.
14. TC 22	,, ,, ,,		Cotton/Nylon blend with foil and CQ permeation barrier coating.
15. TC 21	,, ,, ,,		Nylon face/cotton interlock and CQ permeation barrier

RATG: Performance Rating - 10 excellent and 0 very poor
Performance rating based on estimated permeation resistance.

TABLE III

TASK 3. RESPO 21 SOFT SHELL CONCEPT:

TRADE NAME	DESCRIPTION	RATG	COMMENTS
1.Nylon/Spndx 82% 18%	Darlington Corporation New York, NY 10018 212- 279 7733	2	Good Stretch, no film on top
2.Nylon/Spndx 85% 15%	,, ,, ,,	2	,, ,, ,,
3.Nylon/Spndx 80% 20% Ureth.Laminate	,, ,, ,,	5	Good stretch with film on top. Thick laminate
4.Nylon/Spndx 85% 15% Ureth. Laminate	,, ,, ,,	5	,, ,, ,,
5. Lycra Laminate with urethane	Fabrite Corporation Woodridge, NJ 07075 201-777 1406	9	Good stretch and light weight. Selected for prototypes
6.Polyester urethane laminate	,, ,, ,,	3	poor stretch
7.Ny/ureth/Ny	,, ,, ,,	3	poor stretch
8.Nomex/ureth	,, ,, ,,	4	no stretch
9.Polyurethan PE 192 20 mil thick	Deerfield Corporation South Deerfield, MA 413-665 7016	6	not optically clear but good strength
10.Polyurethn PF 193 55 mil thick	,, ,, ,,	6	,, ,,

RATG: Performance Rating - 10 excellent and 0 very poor
Performance rating based on estimated permeation resistance.

Table III. Continued.............

TASK 3. RESPO 21 SOFT SHELL CONCEPT:

TRADE NAME	DESCRIPTION	RATG	COMMENTS
11. Ny/Spndx 80% 20% style 2208 latex coated	Darlington Corporation coating was done by UDC PIB:Burke-Palmason Chem. Pompano Beach, FL33069	6	Good Stretch, Polyisobutylene (PIB-500) & natural latex coating
12. Ny/Spandx 80% 20% style 2208 latex coated	Darlington Corporation coating was done by UDC BL-100: Burke-Palmason ,, ,, ,,	7	Good Stretch, Butyl (BL-100) & 104L natural latex coatings
13. Ny/Spandx 80% 20% style 2208 latex coated	Darlington Corporation coating was done by UDC TN latex: Ausimont Corp. Morristown, NJ07962	8	Good Stretch, TN Fluoropolymer latex and 104L natural latex coating
14.Kalrez Film 16 mil thick	DuPont Wilmington, DE 19898 800-527 2601 (Tech) 800-441 9494 (sales)	8	Excellent permeation Barrier
15.Kalrez Film 42 mil thick	,, ,, ,,	8	,, ,, ,,
16.Ny/coated with urethane denier 200	Mann Industries Framingham, Mass. 508-879 6366	3	poor stretch
17.Cordura/70D Supplex coated with urethane	,, ,, ,,	3	no stretch
18.Butyl Compd	Exxon Corporation Linden, NJ07036	7	,, ,, ,, Standard type matl for agent protectn
19.Close cell Foam	Voltek Corp. Lawrence, MA 508-685 2557	4	Opaque material. Useful for internal seals between skin and mask material

RATG: Performance Rating - 10 excellent and 0 very poor
Performance rating based on estimated agent protection capability.

TABLE IV

TASK 4. TRANSPARENT FACEPIECE:

Materials for Seal:

TRADE NAME	DESCRIPTION	RATG	COMMENTS
1 .Kraton D2120	Shell Chemical Company Houston, TX77252 1-800 323 3405	5	poor clarity, rubbery thin films
2.Kraton D2121	,, ,, ,,	5	,, ,,
3. Kraton D2730	,, ,, ,,	5	,, ,,
4. Kraton D2731	,, ,, ,,	5	,, ,,
5. Kraton G2730X	,, ,, ,,	5	hazy film (enclosed with final report)
6.Kraton RP6549	,, ,, ,,	7	clear film (enclosed with final report)
7. Kraton G2712	Caldwell Gasket Inc. Auburn, Ky 42206 502-542 4118	6	hazy sheet (enclosed with final report)
8.Kraton D2104	Film made by UDC	8	good clear film
9 .C- Flex 10 mil thick	Concept Polymer Technology 800-541 6880	6	A Kraton matl with silicone modification.

RATG: Performance Rating - 10 excellent and 0 very poor
Performance rating based on estimated permeation resistance.

Table IV. Continued.............

TASK 4. TRANSPARENT FACEPIECE:
Materials for Facepiece Structure:

TRADE NAME	DESCRIPTION	RATG	COMMENTS
10.Polyurethn TF 700 2.5 mil thick	Tuftane Inc. Gloucester, MA01930 508-281 1300	6	not optically clear but good strength and rubbery film
11.Polyurethn TF 410 4 mil thick	,, ,, ,,	6	,, ,,
12.Polyurethn MP 1880 20 mil thick	JPS Elastomeric Inc. Northampton MA01060 413-586 8750	7	Optically clear, and good strength film
13.Polyurethn MP 1890 5 mil thick	,, ,, ,,	7	,, ,,
14.Polyurethn MP 1880 5 mil thick	,, ,,	7	,, ,,
15.Polyurethn MP 1890 40 mil thick	,, ,, ,,	7	,, ,,
16.Polyurethn P 1880 35 mil thick	,, ,, ,,	7	,, ,,

RATG: Performance Rating - 10 excellent and 0 very poor
Performance based on estimated agent resistance and optical clarity.

Table IV. continues........

TASK 4. TRANSPARENT FACEPIECE:

Materials for Barrier Layer:

TRADE NAME	DESCRIPTION	RATG	COMMENTS
17.Aclar film Type 22A 1.5 mil thick	Allied Signal Corp.	7	Optically clear, and have excellent permeation barrier
18.Aclar film Type 22A 5 mil thick	,, ,, ,,	7	,, ,,
19.Aclar film Type 22C 7.5 mil thick	,, ,, ,,	7	,, ,, ,,
20.Aclar film Type 22C 10 mil thick	,, ,, ,,	7	,, ,,
21.Tedlar film Polyvinyl fluoride	DuPont Company Wilmington, DE19898 800-441 9494	7	good permeation barrier proper. and hazy
22. TPX films Polymethyl pentene 12 mils thick	Mitsui Plastics, New York, NY10166 212-878 4462	7	excellent permeat -ion barrier prop.
23.Polypropyln 5 mil thick	Hercules Incorporated Wilmington, DE19894 302-995 3000	8	optically clear, good permeation barrier properties
24.Tefzel film TFE copolymer 20 mil thick	DuPont Company Wilmington, DE19898 88-441 9494	9	good optical clarity surface treated for bonding. Excellent permeation barrier
25.FEP film 2&5 mil thick	,, ,, ,,	9	,, ,,

RATG: Performance Rating - 10 excellent and 0 very poor
Performance based on estimated agent resistance and optical clarity.

Table IV. continues........

TASK 4. TRANSPARENT FACEPIECE:

Materials for Barrier Layer:

TRADE NAME	DESCRIPTION	RATG	COMMENTS
26. Saran Wrap Type 560 10 mil thick	Dow Chemical Company Granville, OH 43023 614-587 5480	7	Good optical clarity and permeation barrier properties
27. Saranex Type 14 2 mil thick	,, ,, ,,	7	,, ,,
28. Saranex Type 15 40 mil thick	,, ,, ,,	7	,, ,,

RATG: Performance Rating - 10 excellent and 0 very poor
Performance based on estimated agent resistance and optical clarity.

Table V

Agent Tests On Coated Polycarbonate - Battelle Data

GB

PAD SPECIMEN #	SUPPLIER IDENTIFICATION	PRE AGENT AREA OBSERVATION	AGENT EXPOSED AREA OBSERVATION
1	LTC5000	Pits	Translucent circle
2	LTC5000	----	Translucent markings
3	LTC5000	----	Translucent markings
4	LTC5000	Pits	Translucent markings
5	LTC5000	----	Translucent markings
6	TS3897-63A	Hazy	NC
7	TS3897-63A	Hazy	Translucent circle
8	TS3897-63A	Hazy	Translucent circle
9	TS3897-63A	Hazy	Translucent circle
10	TS3897-63A	----	Translucent circle
11	XW-121	----	Translucent circle
12	XW-121	----	Translucent circle
13	XW-121	----	Coating degradation
14	XW-121	----	Coating degradation
15	XW-121	----	Coating degradation
	Owens Illinois		
16	GR 651L	----	Coating degradation
17	GR651L	----	Coating degradation
18	GR651L	----	Crescent shaped opaque marking
19	GR651L	----	Crescent shaped opaque marking
20	GR651L	----	NC
21	44961-12-1-20-1A	Pits	
22	44961-12-1-20-1B	Pits	
23	44961-12-1-20-1C	Pits	
24	44961-12-121 A	Pits	
25	44961-121 J	Pits	
26	Exxane S26	Pits	Degradation
27	Exxane S26	Pits	Degradation
28	Exxane S26	Pits	Degradation
29	Exxane S326	Pits	Degradation
30	Exxane S326	Pits	Degradation
31	Norland 81	Streaky, bubbles	NC
32	Norland 81	Streaky, bubbles	Agent area observed but no degradation
33	Norland 81	Streaky, bubbles	NC
34	Norland 81	Streaky, bubbles	NC
35	Norland 81	Streaky, bubbles	NC
36	Owen Illinois	Slick surface	Halo
37	Owen Illinois	----	Crescent marking
38	Owen Illinois	Did not accept	Halo
39	Owen Illinois	Marking pen	NC
40	Owen Illinois	Marking pen	NC

PAD SPECIMEN #	SUPPLIER IDENTIFICATION	PRE AGENT AREA OBSERVATION	AGENT EXPOSED AREA OBSERVATION
1	Photoglaze 63A	Hazy, pitting	Crazing and degradation
2	Photoglaze 63A	Hazy, pitting	Crazing and degradation
3	Photoglaze 63A	Hazy, pitting	Crazing and degradation
4	Photoglaze 63A	Hazy, pitting	Crazing and degradation
5	Photoglaze 63A	Hazy, scratches	Crazing and degradation
6	Norland 81	Streak lines, Pitting	Crazing and degradation
7	Norland 81	Streak lines, Pitting	Crazing and degradation
8	Norland 81	Streak lines, Pitting	Crazing and degradation
9	Norland 81	Streak lines, Pitting	Crazing and degradation
10	Norland 81	Streak lines, Pitting	Crazing and degradation
11	Battelle-12-1-21-1G	Pitting	Raised opaque surface
12	Battelle-12-1-21-C	Pitting	Raised opaque surface
13	Battelle-12-21-1-H	Pitting	Raised opaque surface
14	Battelle-12-21-1-K	Pitting	Raised opaque surface
15	Battelle 12-1-20-1	Pitting	Small opaque raised dots
16	Exxene	Scattered pitting	Translucent, raised circle
17	Exxene	Scattered pitting	Opaque markings
18	Exxene	Scattered pitting	Opaque markings
19	Exxene	Scattered pitting	Clustered opaque areas
20	Exxene	Scattered pitting	Translucent raised circle
	Owens Illinois		
21	6R653L	Marking ink did	NC
22	6R653L	not adhere	Small opaque area
23	6R653L	to surface	Small opaque area
24	6R653L		NC
25	6R653L		Small opaque area
26	Lensguard 21TC-5000	Coating irregular	Raised opaque circle
27	Lensguard 21TC-5000	Coating irregular	Raised opaque circle
28	Lensguard 21TC-5000	Coating irregular	Raised opaque circle
29	Lensguard 2LTC-5000	Coating irregular	Large opaque area
30	Lensguard 2LTC-5000	Coating irregular	Large opaque area
	Owens Illinois		
31	GR651L	----	Two small opaque marks
32	GR651L	----	Small opaque marks
33	GR651L	----	Clustered opaque marks
34	GR651L	----	Small opaque marks
35	GR651L	----	Small opaque marks
36	TW121	----	Large raised area
37	TW121	----	Large raised area
38	TW121	----	Large raised area

HD

PAD SPECIMEN #	SUPPLIER IDENTIFICATION	PRE AGENT AREA OBSERVATION	AGENT EXPOSED AREA OBSERVATION
39	TW121	----	Large raised area
40	TW121	----	Large raised area
41	Mobay MAKROFOL HC500	Scratch marks	Three opaque marks
42	Mobay MAKROFOL HC500	Scratch marks	Numerous opaque marks
43	Mobay MAKROFOL HC500	Scratch marks	Large opaque mark
44	Mobay MAKROFOL HC500	Scratch marks	Opaque mark, turned pink after deconning
45	Exxene S-30-AP	Scratch marks	Opaque marks, turned pink
46	Panelgraphics Vueguards 911	Dust particles in coating	Opaque marks, turned pink
47	GE-HP925 DB-112	Fingerprints	Crazing and degradation
48	GE-HP925 DB-112	Fingerprints	Crazing and degradation
49	GE-HP925 DB-112	Fingerprints	Crazing and degradation
50	GE-HP925 DB-112	Fingerprints	Crazing and degradation
51	AO/Silvue 121	Fingerprints	Opaque mark
52	AO/Silvue 121	Fingerprints	NC
53	AO/Silvue 121	Fingerprints	NC
54	AO/Silvue 121	Fingerprints	Opaque mark
55	Gentex 20	Fingerprints	Opaque mark
56	Gentex 20	Dust particles in coating	NC
57	Gentex HC-20	Dust particles in coating	Three opaque marks
58	Gentex HC-13	Fingerprints and dust particles in coating	NC
59	Gentes HC-13	Fingerprints and dust particles in coating	NC
60	Gentex HC-13	Fingerprints and dust particles in coating	NC

NC: No crazing or degradation or color change

Log 159 - Coated Polycarbonate Plates

Polycarbonate plates were exposed to agent. After 1440 minutes agent area was deconned and observations made.

Agent	No. of Specimens	Observations
HD		
FX174	5	NC
FX174-5	5	NC
FX 167-82	5	NC
GB		
FX174	5	NC
FX167-82	4	NC
	1	Translucent area

NC = No degradation or crazing on agent exposed area.

properties), to more accurately reflect part properties. Another resin supplier developing a design engineering database is Dow Chemical.

Independent databases are tapping expanded data from resin suppliers. Knetz of IDES says his software will include information on 20,000 resin/chemical interactions by the end of the year, including temperature and time conditions. By mid-1991, the company expects to provide a weatherability database as well as data on tensile creep.

Useful tools, or computerized misinformation?

At least three firms supply independent computerized data sheet and resin cost information. Most of the data are single-point properties culled from supplier literature covering about 12,000 material grades. Users of such systems vary from resin suppliers to large consumers of plastics like Motorola, compounders, and a handful of processors, yet opinions differ on the utility of the information provided.

"Systems derived from materials supplier data are simply computerized ways of getting unreliable information, and are suitable for crude screening only," says Al Murray, mgr. of exterior systems research and development for Ford Motor Co., Dearborn, MI. Properties presented, particularly those of reinforced compounds, contain testing errors as high as 50%, he says. "Better analytical tools are needed if plastics are to continue replacing metals in structural roles." (Ford is developing its own resin database, to include testing from suppliers beyond data sheet information.)

Jim Heaton, pres. of California Technical Plastics, Garden Grove, CA, says that the CenBase system from Infodex/Wiley is "an invaluable tool" for working with customers who may be unfamiliar with plastics. "Many companies come to us with pretty firm ideas of what material will work best, having been influenced by resin companies, but the system helps us to identify different resin options of cost vs. performance," he says. "Most molders are hesitant to specify materials, but the system allows us to keep track of hundreds of grades; so we specify resins for about 80% of our tools."

Most resin companies recommend prototyping before production, but they report growing use of computer-aided engineering software—particularly structural simulations and melt flow analysis—to assist in the design of parts that meet mechanical strength requirements while processing well. Many suppliers use Abaqus, a structural analysis code from Hibbitt, Karlsson & Sorenson, Providence, RI, in conjunction with process simulation programs. "Abaqus is effective for thermoplastics because of its nonlinear loading capabilities," says Mehta of Mobay.

Despite the fact that most CAE techniques are experimental, take time for iterations, and have a margin of error, resin suppliers are upgrading data to complement CAE analysis. Minnichelli of GE says his company's database includes a "radial flow predictor" to provide more realistic melt flow data than spiral flow testing. "Based on finite element analysis, the software models disk flow, i.e., a constantly expanding melt front, that is more translatable to actual parts," he says. ❑

Figure 1 : Various Materials Database

Database	Supplier	Resin grades	Format/price	Remarks
CenBase	Wiley/Infodex (New York, NY)	12,700	Disk, $1200/yr. with quarterly updates; $550 without.	Includes metals, composites and fibers.
International Plastics Selector	IDES/D.A.T.A. (Laramie, WY)	12,600	Disk, $695 with updates; $495/yr. without.	Will be supplemented with chemical resistance, weatherability, creep.
Plaspec	Bill Communications (New York, NY)	11,000	Online, $1000/yr. plus use charges.	Processing (rheology) data being added.
Engineering Design Database	GE Plastics (Pittsfield, MA)	471	Online, no charge.	Includes extensive data on creep and modulus.
Polyfacts	DuPont (Wilmington, DE)	200	Online, no charge.	Covers stress/strain, property vs. temperature, other capabilities.
Engineering Properties on Screen (EPOS)	ICI Advanced Materials (Exton, PA)	676	Disk, no charge.	Provides graphical sorting capabilities.
Campus	Mobay (Pittsburgh, PA)	140	Disk, no charge.	Standardized data based on ISO tests.
Campus	BASF (Parsippany, NJ)	160	Disk, no charge.	Includes viscosity profiles, creep curves, aging behaviors; ISO standards.
Fast Focus	Hoechst Celanese (Summit, NJ)	228	Disk, no charge.	Contains stress/strain graphs, tool design guide.
Thermofile	Thermofil (Brighton, MI)	445	Disk, no charge.	Online system in 1991.

Figure 2

12/89

Hood Design

Dip Coat Concept, H.S. Katz

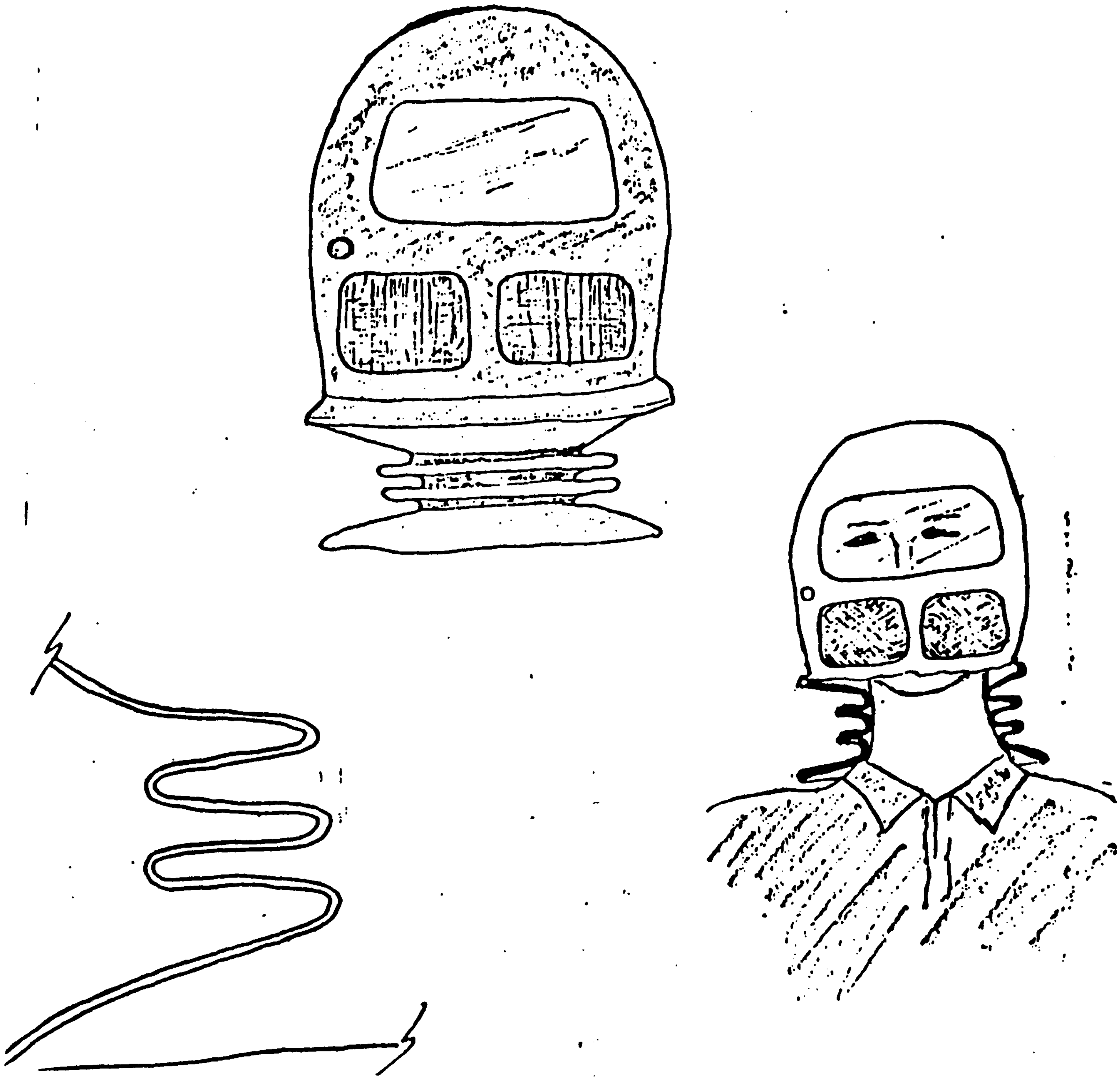


Figure 3.
Israeli Plastic Chemical Warfare Protection Suit

By SABRA CHARTRAND

Special to The New York Times

KIBBUTZ HAZOREA, Israel, Aug. 26 — Hadar Polak was ambling past a bicycle rack, looking like a primitive astronaut in the plastic chemical warfare protection suit he was demonstrating, when a friend drove past and shouted at him, "Don't publicize our factory too much, or we'll be Saddam Hussein's No. 1 target!"

Mr. Polak's factory is a large plastics plant on this kibbutz in the center of Israel, near Megiddo. In one corner of the huge complex, kibbutz engineers have taken a design for nylon food wrap and developed a thin sheet of plastic that is resistant to mustard gas.

The plastic is used to make protective suits — pants, hooded jackets and gloves — for soldiers, firefighters and first aid and emergency workers to wear in the event of a chemical-weapons attack. Kibbutz Hazorea has been selling t[illegible] plastic to the Israeli Defense Minist[illegible] years.

[illegible]

that many soldiers in the gulf.

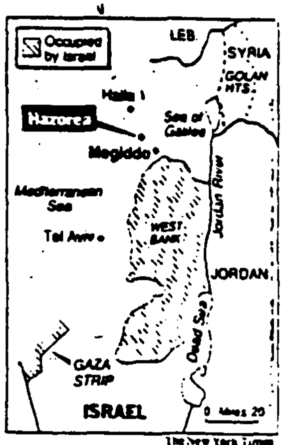
Kibbutz Hazorea is one of several subcontractors employed by the Defense Ministry to produce an array of chemical-warfare defense gear — gas masks, protective clothing, antidote drugs, chemical-detection sensors and alarms, mobile laboratories and decontamination equipment.

The Government has been amassing this defensive equipment since the 1960's. Stockpiling began in earnest after the 1967 war, when the Israeli Army captured Egyptian chemical-weapons stores in the Sinai desert and got a look at what they might be up against in the years ahead.

The military now says it has several million gas masks and anti-chemical weapons kits, which include antidote syringes, detection litmus paper and decontamination powder. It says its stockpile is sufficient for each person in Israel and that it is still trying to obtain enough similar protective gear for Palestinians in the occupied territories.

Again Prepared for War

Still, even knowing that the protective equipment is at hand, a low-level sense of fear permeates Israel these days. For almost 40 years, Israelis have been told to keep the millions of



The New York Times

Kibbutz Hazorea makes a plastic resistant to mustard gas.

bunkers that dot the country ready for war. At the first word of enemy bombs, they are to scurry into the subterranean shelters that are a mandatory part of every home built since 1956.

Now suddenly, the menace of Iraq's chemical weapons has sent Israelis looking for safety as high above the ground as possible — away from heavy gases that, after detonation, fall quickly to the earth.

The army says casualties can be reduced 50 times if civilians and soldiers put on gas masks within 30 seconds of a chemical attack. But this means that the military's untested mask distribution plans, chemical detectors and monitors have to be in place and working smoothly.

The military has been hesitant to hand out the masks before an attack is imminent because it says people will not take proper care of them. But public awareness of ways to deal with chemical weapons is mounting. The Education Ministry just announced that Israel's schools would conduct gas-mask drills and teach a million schoolchildren how to respond to attack. Newspapers have published the Civil Defense Authority's emergency guidelines, including an English translation in The Jerusalem Post on Sunday.

At Kibbutz Hazorea, members of the collective who work in the factory say producing the protective plastic suits helps reduce their own fears.

"We can see that we are making something which will cut down the affect of chemical weapons," says Rami Harpaz, the factory's general manager. "And at a time like this, the fact that we are working and contributing to the defense effort helps us stay calm and keep things in perspective."

The plastic sheets that are ultimately cut into the protective suit pattern and then sewn together with heat seals roll off a huge machine not far from a sign that declares: "We work here without defects." Each sheet is one-tenth of a millimeter thick and looks and feels like ordinary transparent plastic.

"Regular plastic doesn't stop gases from going through," says one of the suit's designers, Yiftah Nir. "Our suit is a combination of materials. The plastic in the middle is a barrier material that prevents the gases from penetrating; then there are two adhesive layers, and two heat-sealing layers."

Greenhouse Effect

The suit has been tested with mustard gas in a Defense Ministry laboratory, and for wear and comfort by kibbutz members. Mr. Harpaz says the pants, jacket and gloves passed the gas test. But the wearer is dreadfully uncomfortable after only about 20 minutes.

"The problem of the suit is it doesn't breathe, so you start to sweat to death pretty quick," Mr. Harpaz said. "You really can't wear it any longer than two hours, although in our tests the suits stands up for at least six hours."

With a pause and a smile he added: "It might last longer than that, but our members who test it only work six-hour shifts. After that, they take the suit off and go home."

Outside, after about five minutes, the sample suit worn by Hadar Polak started to look like the windows of a greenhouse. The plastic steamed up, and condensation began rolling down the inside. Mr. Polak's face was drenched.

Considering the Alternative...

"I'd wear this thing if there was a war," he said. "I wouldn't have any choice. But I'd be very unhappy. It's

Rina Castelnuovo for The New York Times

Hadar Polak modeling the plastic chemical warfare protection suit that his company manufactures on Kibbutz Hazorea in Israel.

really uncomfortable, really hot."

Many of the firefighters, first aid workers and volunteers who are expected to help Israelis recover from a chemical warfare attack will suffer the same discomfort. The suit may protect them from chemical fallout, but it will make firefighting, clearing rubble and aiding the injured difficult at best. And

American soldiers serving in Saudi Arabia, where the temperatures are even higher, will be no less uncomfortable.

"It's hot, but not any hotter than army gear and a helmet," said Eliezer Shurow, a kibbutz member. Then he added: "Well, I'd rather be hot than — you know."

Arabs to Discuss the Crisis

Special to The New York Times

TUNIS, Aug. 27 — Arab diplomats here said a quorum had been reached today to call a disputed meeting of Arab League foreign ministers in Cairo on Wednesday to discuss the crisis in the Persian Gulf region.

Eleven of the Arab League's 21 members said today that they would attend the special meeting, which was scheduled as a follow-up to the Aug. 10 summit meeting that voted to send an Arab force to Saudi Arabia. The 11 are among the 12 that voted for the force. The 12th is Morocco, which is expected to attend as well, the diplomats said.

The meeting may further divide the Arab world, as it is uncertain whether the rest of the league members will attend. Some, like the Palestine Liberation Organization, said they would not, the diplomats reported.

Egypt pressed for the meeting, which was originally scheduled for May 26 but was pushed back to give time for peace negotiations to develop.

Only three Arab countries — Egypt, Syria and Morocco — have actually sent forces.

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Figure 4.
Israeli Gas Mask for Children

Associated Press

Ten-year-old Einat Yocpaz giggles as an Israeli soldier helps her try on a gas mask for children during a civil defense demonstration in Ramat Hasharon, north of Tel Aviv

Addendum 1

DIP MOLD CONCEPT

PROCEDURE:

At the meeting on Jan. 8th, we showed a miniature hood model based on a dip-molding concept. The bond between the polyurethane lens and latex fabric was poor. We tried several adhesives and bonding procedures. A good bond was obtained by the following method: The polyurethane lens surface was primed with Dow Corning 1205 and then the fabric was stretched over the mandrel, Witcobond W290H (urethane adhesive) from Witco Chemicals was applied at the edges of the lens. When we then applied a natural rubber latex to the partially cured adhesive, an excellent bond was obtained between the coated fabric and the insert.

We evaluated different types of latex materials for coating to obtain maximum stretchability and permeation barrier properties.

All trials with full size mandrels to this date (July 26, 1990) were made by use of 104 L natural rubber latex from Firestone. Most of these were on the full size mandrel that Mr. Grove gave us on May 23rd. This mandrel was very heavy and difficult to handle, so we had a hole drilled in the center bottom to make it a little lighter and easier to handle. Our fabrication method was to cover the mandrel with a stretchable fabric. Then the lens, filter and flapper valve, which had been coated with the silane primer, were slipped inside the stretched fabric over the mandrel. We then flow coated the fabric with the natural rubber latex. Trial No. 2 through 5 involved 6 thin coats, with about 30 minutes dry time between coats, and the first and last coat had some talc added to the latex. The final coated part was cured in an oven at 200°F for about 20 minutes. After removal from the mandrel, masking tape shields were removed by a careful razor cut along the perimeter and peeling off of the outer surfaces of the lens, flapper valve, and filter.

We tested the trial masks for ease of donning and comfort. They could be easily be pulled over our heads, and it seems that breathing and vision should be satisfactory. We think these are good preliminary demonstration samples of this type of fabrication method that should be considered for future use. However, it is important to keep in mind that production units of this type would be made by significant modifications of our trial methods. For example, dip coating rather than flow coating would be used, since this could be automated on a continuous line where multiple coatings would be applied along a conveyor belt. The fabric preform would be made in large quantities at a low price by a knitting or braiding process, or they could be heat sealed in multiple units per the one demonstration sample that we have submitted in our July 26th meeting. The masking material on the inserts (lens, flapper valve, filter, etc.) will be cut off by use of steel rule or clicker dies in a fast time cycle.

It is important that the fabrication process and design should be co-ordinated. For example, the mandrel that would be used for this process should have surface cavities where inserts such as the filter or flapper valve would be placed, before the mandrel is covered with fabric and placed onto the conveyor for the coating cycle. Also, inserts such as the flapper valve should be designed for this process so that a steel rule die can readily be used to cut off the shields that will be used to prevent coating the central surfaces of the part.

Addendum 2

A letter received from Mr. Charles Shoemaker is given below:

"Introduction:

Ever since the initiation of Chemical Warfare, three factors have controlled the concept design of military protective devices:

1. Human physiological considerations, such as face shape and size and respiratory and skin considerations.

2. The chemical, physical and toxicological characteristics of chemical agents

3. The properties of available materials of construction and the ingenuity of the mask designer in using the available materials in designs which least impede performance, physiological burdens and compatibility with military equipment.

Considering the current status of each of these factors indicates the potential for significant improvement in design and performance.

1. There has been no significant change on the human using the equipment. Face sizes and shapes have not changed nor have the requirements for respiratory tolerance, heat tolerance, etc.

It can be concluded then that from the standpoint of the mask designer, no new avenues of design change can be found which allow significant change in facepiece design.

2. Ever since the inception of chemical warfare, vapors and aerosols as well as liquid chemical agents have been employed and while there have been changes in toxicity and persistence, these factors generally have been handled by the mask designer through relatively minor changes to the facepiece with the major changes required being accomplished through the design of improved filter, personnel shelters, etc.

3. Thus materials of construction are the principle basis for significant changes in facepiece design.

The goal of this program has been to develop, locate and recommend materials which will allow significant improvement in facepiece design through the exploitation of these materials.

Some overall considerations:

Use of thermoplastic materials which exhibit heat sealing, heat forming and ease of decontamination and which were described in this study offer the potential for allowing significant changes in facepiece design and fabrication changes:

1. Thermoplastic materials can be fabricated into facepieces without the use of expensive steel molds. This allows the mask designer the opportunity of fabricating virtually finished models for test at a low cost using inexpensive tools. In actual production, the cost of production models will be less and additionally companies other than conventional rubber molders can qualify as production sources.

Thermoplastic materials such as those proposed under this program offer the potential for the design and fabrication of close fitting hood-mask combinations yet provide adequate resistance to liquid chemical agents. Components such as lenses, valves, neckseals and harness hardware can readily be assembled as secondary activities. The low cost potential allows consideration of one time use thus avoiding contamination and decontamination following attack.

2. The materials developed under this program include ones which have the potential for being water white and meeting optical requirements either in a unifabricated or lens bonded on design concept. Rigid lenses can be bonded by heat or chemical adhesives to afford maximum field of view and minimized weight and bulk by eliminating attachment with metal eyering.

3. Use of foam materials developed under this program will enhance improvement in the seal and thus the protection afforded by the mask. Additionally, use of several sizes of foam faceseals may allow one size facepiece to accommodate all face sizes through assembly of the correct size seal to the facepiece at company or squad level.

The generalized guidelines stated above can be utilized in generating specific designs such as:

1. Unimolded or cast facepieces in which the lens is formed during the molding or casting and secondary components such as valve seals, harness buckles, etc., can be insert molded or insert cast. Thus in one basic operation, an essentially complete facepiece is produced.

2. Dipped or molded faceblanks less lenses can be fabricated by using chemical agent resistant butyl compounds thus allowing the use of an overgarment attached hood rather than a mask attached hood.

3. Combinations of thermoplastic materials can be employed in hood designs which offer great chemical agent resistance because of their synergistic interaction as described in progress reports under this contract."

Charles J. Shoemaker

APPENDIX I.

- Narrative summary of meetings and conferences

On January 8,1990, the first meeting on this program took place at Edgewood Arsenal, Berger Lab. We planned that as an informal discussion of the program background information, objectives, tasks, and plans for meeting and exceeding the SOW objectives. We had also shown a number of samples that we had already received, and discussed a hood dip-fabrication process that could lead to lower cost and better protection.

On March 20, 1990, Harry S. Katz, Dr. John A. Brown and Dr. Radha Agarwal visited Exxon Chemical Company, Linden, N.J. to discuss their butyl rubber technology, and were given the latest status report on the use of butyl rubber for protective clothing. Those who were present in the meeting were Donald F. Kruse, Senior staff engineer, Dr. Irwin J. Gardner, Research Associate and Robert C. Pydak, Engineering Associate. We had stated to the group of scientists that we wanted facts for a report on recommended materials for CB protection. We had told them that presently, butyl rubber was considered to be the best current material for clothing applications, and we wanted to get a status report on butyl rubber and improvements in either material or processing. Although butyl rubber has performed well for hood applications, there have been some problems with its use in clothing. In particular, the Butyl TAP Suits have encountered cracking and flaking problems. There have been crazing and premature failures, typically in the armpits and crotch areas. Exxon had developed improved butyl formulations. Some of these had a treated talc filler instead of the standard mineral filler and initial results indicate less moisture absorption, better tear strength and physical properties with lower permeation rates. Mr. Puydak discussed the new Exxon line of thermoplastic elastomers that was based on butyl rubber. The Trefsin products had the basic properties of butyl, but could be fabricated by the more convenient thermoplastic methods rather than those were used in conventional rubber procedures. This could provide many benefits for the use of these materials in CB protection applications. Exxon was in the process of developing a new material named EMDX 89-1. This was a copolymer predominantly based on isobutylene and with a new comonomer. This product was very close to Butyl rubber in properties. Permeation barrier properties of EMDX 89-1 was the same as Butyl rubber but the new material had better high temperature stability. This product was not available in the market at that time but they were planning to market it soon.

On May 23rd, Mr. Harry Katz had an informal meeting with Mr. Corey Grove and other people involved. In the meeting, Mr. Katz submitted samples coated with Butyl latex and Polyisobutylene, some of these in combination with layers of natural rubber. Mr. Katz also mentioned the possible use of DuPont Kalrez film and samples with different levels of fluorine surface treatment by Air Products.

Our third meeting on this program at Edgewood Arsenal took place on July 26, 1990. We had planned this as a discussion of the program objectives, tasks, and work completed so far on this program so that we were certain to fulfill or exceed the SOW objectives. We had shown a number of samples that we had already received, and discussed a hood dip-fabrication process that could lead to lower cost and better protection.

Mr. Katz attended an American Chemical Society, Rubber Division meeting in Washington on October 11th, 1990, primarily to obtain information that would be pertinent for this CBIAC program. During this meeting, some papers were presented on TPE's, which may be useful for tasks in this program. Specific details have been discussed in Section 2.e of this report.

APPENDIX II

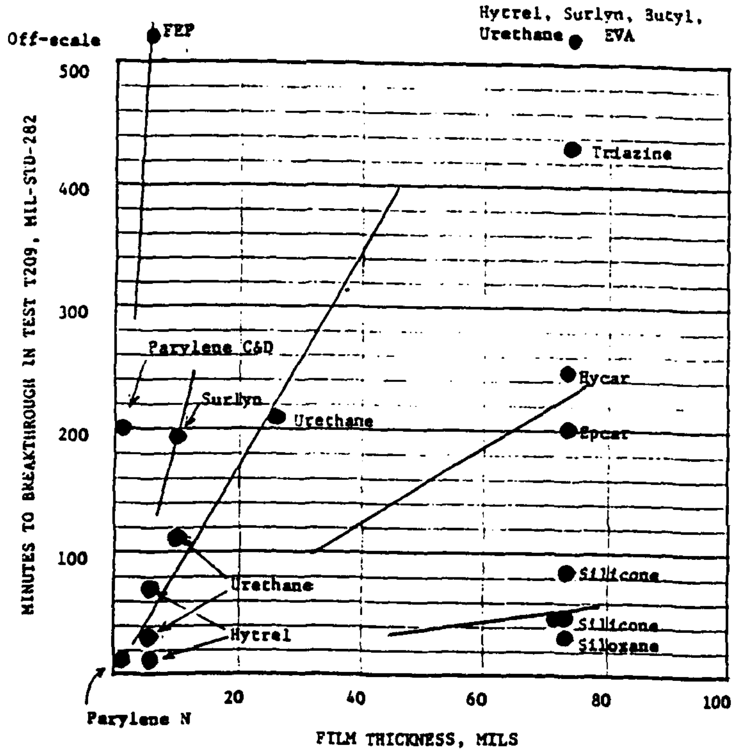
AGENT PENETRATION CORRELATIONS

Several years ago, we collected and correlated a body of agent film penetration data that had been developed on earlier mask development programs. The resulting report is appended here because the findings are still pertinent to the RESPO 21 program.

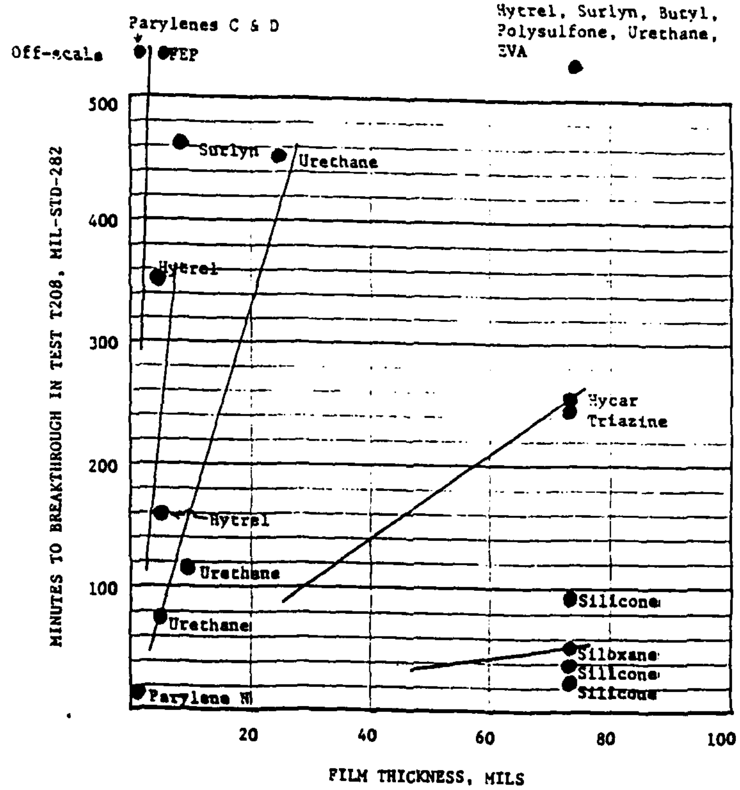
The raw data were obtained from the Respirator Section of the Physical Protection Branch of Edgewood Arsenal. The Respirator Section warned that the data should be interpreted with caution, pointing out that most of them are single determinations and were only preliminary scouting tests in the first place. We appreciate these reservations, and we realize that single tests are always subject to defeat by such things as pinholes in thin films or instrument detector failure; nevertheless it is perfectly valid to base preliminary conclusions on correlations of such data to the extent that the correlations are self-consistent and reasonable. A number of self-consistent and reasonable correlations can be extracted from these data.

The following figure plots time to breakthrough of Agent GB and Agent HD vs. film thickness for a number of polymer films, and indicates several tentative correlations. The correlations are not quite as arbitrary as they might seem at first glance; the lines all reasonably ought to go through the origin, since zero film thickness would give zero breakthrough time, and one would certainly expect breakthrough time to increase monotonically with film thickness. In general, the silicones appear to be poor choices as barriers to GB. The urethanes look much better, but would still be expected to give only about 200 minutes protection at 10 mil thickness with a liquid contact challenge. The Hytrels (DuPont Polyesters) are even better, and the fluorinated ethylene-propylenes and Parylenes C and D are best of all.

PENETRATION BY AGENT HD



PENETRATION BY AGENT GB



PENETRATION RESISTANCE OF VARIOUS PLASTIC FILMS TO HD AND GB

Plastic Film	Minutes to breakthrough, T-208/9 HD	GB
Alkylene oxide (Dow 37)	15	152
Alkylene oxide (Dow 38)	15	190
Alkylene oxide (Dow 39)	15	230
Alkylene oxide (Dow 40)	15	400
Nylon + Saranex	480+	480+
Saranex	480+	480+
Teflon	480+	480+
Capran 77c	480+	480+
Polyamide	480+	480+
Hytrel 6350, 5 mil	68	350
Hytrel 4055, 5 mil	10	158
FEP-200, 5 mil	480+	480+
Parylene C, 1 mil	200	480+
Parylene D, 1 mil	200	480+
Parylene N, 1 mil	10	10
Upjohn Pellathane 2103-80A, 5 mil	30	70
Surlyn, 10 mil	195	480+
Kraton G, 10-20 mil	115	420
EVA, 5-10 mil	10	200
Polycarbonate, 10 mil	200	480+
Goodrich Estane, 10 mil	5	8
Aclar 22A, 1.5 mil	85	60
Upjohn Pellathane 2103-80A, 10 mil	45	110
Upjohn Pellathane 2103-80A, 25 mil	210	450+
Transparent silicone rubber (Dow X42665) 100 mil	85	160
Hard coated polycarbonate, GE. 125 mil	480+	480+
Silmethylene (Dow-Corning), 75 mil	113	480+
Silethylene (Dow-Corning), 75 mil	38	219
Fluorel (3M), 75 mil	480+	480+
Kel-F (Penwalt), 75 mil	480+	480+
Mobay urethane E-275, 75 mil	480+	480+
Cellulose butyrate, 75 mil	27	41
C-4 Polymer (Union Carbide), 75 mil	480+	480+
Hytrel 4055, 75 mil	480+	480+
Hytrel 5550, 75 mil	480+	480+
Hytrel 6350, 75 mil	480+	480+
Butyl rubber, 75 mil	480+	480+
Gentex urethane, 75 mil	480+	480+
U.S.I EVA, 75 mil	480+	480+
GE LR-4430, 75 mil	41	36
GE LR-5430.	41	26
GE LR-3320, 75 mil	85	93
Hypalon, 75 mil	480+	480+
Neoprene, 75 mil	480+	480+
EPDM (DuPont), 75 mil	480+	480+
Dow CPE, 75 mil	480+	480+
Dow Triazine, 75 mil	435	240
Dow polypropymethylsiloxane, 75 mil	35	50
Hycar-1014, 75 mil	390	480+
Hycar-1203, 75 mil	480+	480+
Hycar-1000X, 75 mil	250	480+
Hycar-4031, 75 mil	480+	480+
Epcar, 75 mil	200	480+
polysulfone, 75 mil	480+	480+
Surlyn, 75 mil	480+	480+
Dow Silicone-polystyrene copolymer, 75 mil	45	80

PENETRATION RESISTANCE OF COATED SILICONE RUBBER TO HD AND GB

Coating on 75, 80 or 100-mil Silicone slabs	Minutes to breakthrough, T-208/9	
	HD	GB
Fluorel, 2.5 mil	450+	400
Acrylic, 3 mil	230	232
Parylene C, 0.1 mil	117	347
Parylene C, 1 mil	480+	480+
Teflon	34	70
Difluorodichloroethylene	100	250
Dow-Corning 94034	238	296
Dow-Corning 733	240	250
Dow-Corning 94003, 3 mil	210	236
Upjohn urethane, 5 mil	130	400
Capran, 2 mil	460+	460+
Saran, 1 mil	460+	460+
Saranex, 4 mil	460+	460+
SAN, 3 mil	350	450+
Kapton, 1 mil	460+	320
SBR latex, 1 mil	170	420
Cellophane, 2 mil	400+	400+
Acrylic latex, 4 mil	350	450+
Nitrile latex, 3 mil	150	385
Kraton, 25 mil	420	460+
Dow-Corning QR43117, 1 mil	79	107
DuPont E-0358-PV, 3 mil	250	400
Chemglaze 160-162A, 1 mil	135	210
Wil. Chem. Y80-A50, 1 mil	210	210
Capran, 5 mil	430	-
Aluminum oxide,	34	100
Upjohn urethane, 10 mil	450+	450+
Polyester and polyvinylidene chloride	300	450+
2-mil vinyl chloride and 1.5 mil Aclar	450	300
Acrylic and polyvinylidene chloride	425	400
Polyester PE-200	110	~~450+~~
Thermosetting polyester	110	450+
Wil. Chem. urethane and Viton	180	140
Viton	350	155